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SOLAR COLLECTOR SYSTEMS ANALYSIS
USING INFRARED SCANNING TECHNIQUES

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FOREWORD

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SUMMARY

This paper discusses solar energy collector systems analysis using thermography. The research at the Solar Energy Research Institute (SERI) in this area has focused on infrared (IR) scanning techniques and equipment to determine temperature distributions, flow patterns, and air blockages in solar collectors. The results of this extensive study, covering many sites and types of collectors, illustrate the capabilities of IR analysis as an analysis tool and operation and maintenance procedure when applied to large arrays.

Infrared analysis of most collector systems showed temperature distributions that indicated balanced flow patterns with both the thermographs and the hand-held unit. In three significant cases, blocked or broken collector arrays, which previously had gone undetected, were discovered. Using this analysis, validation studies of large computer codes could examine collector arrays for flow patterns or blockages that could cause disagreement between actual and predicted performance. Initial operation and balancing of large systems could be accomplished without complicated sensor systems not needed for normal operations. Maintenance personnel could quickly check their systems without climbing onto the roof and without complicated sensor systems.

SECTION 1.0

INTRODUCTION

As solar energy collector systems become more common in the heating and cooling industry, these systems will require operational analysis and maintenance techniques. The collectors must be installed properly, the flow rates adjusted and balanced between arrays, the daily operation and efficiencies monitored, and preventive and periodic maintenance performed. In large arrays of solar energy collectors, one now depends on sensors to obtain the measurements to perform these operations, but sensors require complex electrical systems and computerized controllers, plus expert engineers to operate them. Increased solar energy usage will demand the procedures to be performed by technical personnel because of the cost of labor and the extensive applications problem.

The investigation of solar collector array systems using infrared (IR) scanning techniques is an attempt to extend an analysis procedure from the laboratory [1,2,3] into the general solar collector systems population. The scope of this paper is the analysis of collectors as a subsystem, not the analysis and evaluation of each individual collector and its plumbing. The system analysis is, therefore, qualitative and allows the use of IR scanning or thermographic equipment that also tends to be qualitative in its output. Although the nature of the radiation to be observed and its sources leads to a lack of exact detail in sensing temperature distributions, the researcher can draw valuable conclusions from the data.

SECTION 2.0

THERMOGRAPHY DESCRIPTION

Infrared scanning using thermographic equipment is a heat detecting technique that measures IR radiation to show a temperature distribution across the surface of a material. The emitted radiation is a function of the material's temperature. Thermographic equipment measures the intensity of this radiation (2.0 to 5.6 μm) and shows the temperature distribution on a cathode-ray tube. The image can then be photographed to produce a thermograph. Through the analysis of these pictures, one can see the exact location of differences in temperature. Because one can observe an overall heat distribution, thermography is useful to show malfunctioning collectors or problems of flow rate across the solar array [4].

Several problems must be carefully considered. First, wind can affect the readings shown on the thermographs. A maximum wind velocity of 6.7 m/s is recommended. Second, the ambient temperature range of the IR scanning equipment should be -15°C to 55°C [4]. Third, glass reflects radiation as well as emits it. If reflected radiation from the glass covers on the collectors is undetected, one could make false readings. Also, when the surface is being scanned, one should ensure that the sun's image does not appear in the thermograph. Fourth, and most important, since the glass surface of the collector is not the surface of interest, one must realize that the readings are from the glass itself and may not indicate exactly the temperature from the absorber surface. Correlation to the absorber surface is necessary for accurate interpretation of the thermographs. A study that measured the absorber surface temperatures of solar collectors and simultaneously observed the thermographs of the collector arrays [5] concluded that

the collector absorber temperature distribution was qualitatively displayed in adequate detail by thermographs taken during the collection of the temperature data. This report will extend that laboratory conclusion to the general collector population.

A thermograph (see Fig. 2-1) consists of a scale indicator, a reference chart, and a picture of the temperature distribution. These thermographs illustrate the output of the IR scanning unit when a photograph is taken of the image repeater cathode-ray tube. The scale indicator above the picture designates the maximum range of temperature of the thermograph in degrees Celsius. The reference chart to the left of the picture assigns a value to a specific color code. For example, in Fig. 2-1, 5 represents 5°C and shows that the range of 0.0-1.0 represents a maximum relative temperature difference of that amount. The other figures show possible scales used during this study. By using the picture of temperature distribution, one can compare various temperatures on the surface. Interpretation of the thermograph is relative; however, a calibration of the thermograph may be made if any temperature at one spot on the material is known. Thermographs from the ground-based IR scanning unit can be made in either black and white or color.

The sites used in this study were instrumented so that one could attempt a correlation of temperature readings. Also, if any problems were detected, one could correct them and note operational changes. The author chose instrumented solar demonstration systems projects of the National Solar Data Network (NSDN) [6] for this data comparison. The majority of the thermography study sites are from this system and are located in Colo. and N. Mex. (Table 2-1). However, not all the sites in the NSDN were reported operational during August and September of 1979. The sites at Colorado State University and the Air Force Academy completed the selection. Even though the author chose instrumented sites, very little actual temperature data was collected because of problems with those data collection systems.

SECTION 3.0

DATA ANALYSIS

Solar collector systems analysis using IR scanning techniques proved one can apply this technique to the general population of collectors for analyzing the temperature distributions across their surfaces. One could then extrapolate this temperature difference to decide what flow patterns caused them. Through this correlation one could quickly locate flow problems or air blockages in liquid systems and correct them while one observes the results.

The population of collectors analyzed during this study (see Table 2-1) included both selective and nonselective coated-plate collectors. These systems proved to be applicable to IR analysis because the temperatures on their absorber surfaces are related to the temperatures on the glass covers, both in single and double glazing. Once the absorber temperatures were transmitted to the glass, IR scanning equipment could sense them and display the distribution. The choice of heat transfer fluid either liquid (see Fig. 2-1) or air (see Fig. 2-2), did not negate this thermographic technique.

Evacuated collectors caused the most difficulties when examined with IR scanning equipment. Because the vacuum slows the transfer of energy from the absorber surface to the glass surface, it greatly hampered the observations of any temperature distribution. A large temperature difference between adjacent collector arrays was necessary before the thermographic equipment would display any glass surface differences. Once these were shown, the researchers detected trouble such as completely shutdown clusters.

Compound parabolic concentrators offered very small target areas for one to examine. Glare from nonoptimal concentrators caused problems when the researchers used the equipment to observe temperature distributions. However, the thermographic technique allowed one to observe the distribution of very large temperature differences between collector arrays. Because the collector heated up after the plumbing system was blocked and energy radiated out through the covers over the collector tube, one could detect the temperature level and compare it with other levels.

The exterior of passive structures proved to be a poor target for thermographic analysis. However, once inside the structure, the equipment could spot problems. Even very small temperature differences permitted detection of empty and partially filled barrels, conditions which previously had gone undiscovered.

The examination of the general population revealed that most systems were operating with very few problems. Those few that were discovered tended toward air blockages and flow imbalances (see Table 3-1). The IR scanning equipment twice detected air blockages in large arrays of liquid collectors in both small residential systems and larger apartment-complex systems. Figure 3-1 shows air blockage because of a malfunctioning air vent valve in a liquid system and an air entrapment after stagnation from a shutdown system. The researchers remedied the problem and observed the temperature distributions. Another trouble spot was located on a roof that was inaccessible to a homeowner without using a ladder. The larger problem (see Fig. 3-2) with the apartment-complex was caused by an undetected malfunctioning air vent valve in a liquid system with drain down. This valve allowed air into the plumbing and did not close tightly because of insufficient pressure at the far end of the specific array. This problem was spotted from a distance of two city blocks, from the street in front of the structure and from the roof itself. Significantly, the maintenance personnel had neither seen the leaking fluid on the

roof nor detected any deterioration of performance with almost one-third of the collectors out of action.

Analysis using IR scanning equipment also detected shutdown collector systems from the street locations without one having to climb onto roofs. Thermographic units spotted broken collectors with fractured glazing among a very large array on a commercial application. Finally, even empty water barrels in a passive system did not escape unnoticed.

Using IR scanning equipment on the lower scales, the researchers detected small flow imbalances, other than those caused by air blocks. Correction of these imbalances would lead to a more efficient collector system in which the flow was the same throughout the arrays and at the design levels selected by the original mechanical engineer. If the designed flow through the collectors is not maintained, the efficiency of the collectors will vary to levels other than those selected for the operating conditions. One can correct the flow imbalances while observing the temperature differences between the collectors or between the arrays. When all systems indicate equal flow through evenly distributed temperatures, one can disconnect the adjusting valves and recheck the flow in the future.

From examining many systems of collectors, the researchers learned that most systems maintained by competent personnel with simple control schemes collected solar energy without major difficulties. If control schemes became complicated, the technical personnel reported dissatisfaction with system performance. Simplicity in residential design and control led to collectors that appeared to operate with anticipated temperature patterns and no flow blockages. Minor differences between most collectors did not usually require correction. Major problems seemed to arise from complexity of design, control, or inadequate mechanical design to account for plumbing pressure drops. These

difficulties could have been detected by complex sensor systems or frequent observation by the maintenance personnel, but had gone undetected until scanned with the thermographic equipment. It also detected the minor problem of thermosyphoning that usually requires sophisticated sensors unless it is specifically being examined.

SECTION 4.0

FUTURE APPLICATIONS

In the overall plans for solar energy systems analysis such as those at SERI [8], validation of analysis techniques is important, involving comparison of real data from a large instrumented collector system with predicted performance from a computer program. Often some discrepancies between the two can be expected, but can go unexplained. If the collectors are operating at the desired flow rates with a balanced pattern, they should accurately follow the predicted efficiency and performance curves if system losses are considered. If the designed flow is not maintained at the proper rate, then variations from the desired efficiency can occur. As more systems are analyzed to optimize the output of collectors operating in systems, this discrepancy engenders doubt about the accuracy of the prediction techniques. One could use IR scanning techniques to spot either flow imbalances or air blockages.

An analyst detecting flow imbalances could correct them in two ways. While scanning with the thermographic equipment, he could rectify the flow imbalance to obtain evenly distributed temperatures and fluid flows, or he could change the analytical program code to reflect more closely the reality of the flow distribution. More accurate programs, for instance, could be developed to model the flow differences within large arrays of collectors and to predict their effects on output temperatures for each array. The flow could be balanced on general groups of collectors without the need to install complex sensor systems on each collector in the large array. Thermographic equipment could detect uneven fluid distribution and aid in its correction.

One could eliminate completely blocked inactive arrays from the analytical computer code by subtracting the effected collector area and reanalyzing the system to obtain more accurately predicted performance; this operation would explain any gross difference between the predicted and actual performance without needing to physically contact all the collectors of large arrays and without needing to instrument each one. While observing the effects of the repair efforts, one could clear the air blockage and then make another comparison to see if the system performs predictably. This analysis would help to validate the analytical computer code by detecting problems that cause discrepancies between the predicted and actual performance of large collector arrays.

System configuration investigations could benefit from IR scanning. The plumbing of solar collectors into series, parallel, or combination systems affects the temperatures of the fluids within the collectors, evidenced by the temperature distributions across the various arrays of collectors in different configurations. In the analysis of the effects of series collectors and their temperature rises versus parallel plumbing and its temperature rise, one could employ thermography to display clearly that distribution in large arrays. The effect of one more collector added to a series could be rated by the apparent rise of temperature at that collector when compared to each of the others in the series. One could observe directly the outcome of adding another row of parallel collectors to an existing plumbing system while the flow was being adjusted in the array, the pressure was being adjusted in the system, or the pumps were being added sequentially to the system. Thus, one could correct configuration problems on-the-scene and could avoid future maintenance difficulties.

As numerous solar energy collector systems become operational across the country and as their sizes substantially increase, operations and maintenance will move out of research and into the technical area. The maintenance of large arrays of collectors is

becoming the responsibility not of researchers and solar engineers, but of mechanical personnel and technicians who do not need complex microprocessor-controlled sensor systems to operate a solar collector system at peak efficiency, especially if energy management control systems are already installed in large structures. Those charged with operating very small, widespread systems such as those in many apartment houses need to quickly ascertain the operation efficiency without sensors on every collector or array. Maintenance personnel labor costs make critical the time required to inspect mechanical systems. Operating and maintaining large collector arrays with the aid of thermography conserves time and effort. Infrared radiation scanning would quickly confirm that all collectors appear to be functioning. Without climbing onto the structure, personnel could immediately correct any maintenance problems such as blocked collectors, stuck shutoff valves, stuck air vent valves, accidentally changed flow control valves, completely blocked collectors or arrays, broken glazing, and broken connections or collectors.

Already one asks: How well do solar collector systems perform? Owners and operators have thought everything was functioning adequately when, in fact, many liquid collectors were blocked by air or were not flowing because of pump or valve failures, etc. Thermography would quickly spot gross trouble or confirm that a system or portion of a system was operating. A compiled booklet of thermographs illustrating classic problems would help an owner/operator or maintenance person to correct these problems. Systems analysis using IR scanning techniques allows mechanical technicians to perform periodic inspections or utility company personnel to survey local collector arrays in large numbers or sizes.

SECTION 5.0

CONCLUSIONS

One can use IR scanning techniques to analyze solar collector array systems throughout the collector population. Thermography equipment is accurate enough to qualitatively identify flow imbalances, air blockages in liquid systems, empty water barrels in passive houses, and broken collectors. It can also qualitatively show flow patterns across large arrays of solar collectors. Without climbing onto the roofs, one can employ these techniques to detect problems from great distances. By use of IR scanning equipment one can compare the predicted performance with the actual performance of collector systems, examine the effects of plumbing configurations, and operate and maintain present and future large solar arrays.

SECTION 6.0

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Table 2-1. Analysis Sites

Location	Type of Collector
Yale Elementary School Aurora, Colo.	liquid, flat-plate, selective
Colorado State University ^a Ft. Collins, Colo.	various air and liquid
Colorado Sunworks Passive House Longmont, Colo.	water barrels (passive)
Boulder Post Office Boulder, Colo.	liquid, flat-plate, selective
Solar Test House ^a USAF Academy, Colo.	liquid, flat-plate, nonselective
Albuquerque Western Solar Industries Albuquerque, N. Mex.	liquid, tracking concentrators, selective
Homes by Marilyn Albuquerque, N. Mex.	liquid, flat-plate, nonselective
Animal Control Center Albuquerque, N. Mex.	liquid, tracking concentrators, selective
Base Exchange Kirtland AFB, N. Mex.	liquid, flat-plate, selective

^aNot part of NSDN [6].

Table 3-1. Research Sites Analyses Summary

System	Technical Difficulties Uncovered	Thermography Use Demonstrated
CSU Solar House I	Shutoff module	Evacuated tube examination
CSU Solar House III	Frosted collectors	Residential array examination
Colorado Sunworks	Empty/partially filled water barrels	Passive system examination
USAFA Solar Test House	Inoperative array, closed valves, blocked cluster	Blocked array and cluster detection
Albuquerque Western Solar Industries	Blocked, inoperative array, malfunctioning air vent valve	Resolution of small target (CPC) from distance, blocked array
Homes by Marilyn	Shutoff systems, thermosyphoning	Residential array examination, thermosyphoning detection
Kirtland AFB Exchange	Broken glazing	Very large array examination, broken glazing detection

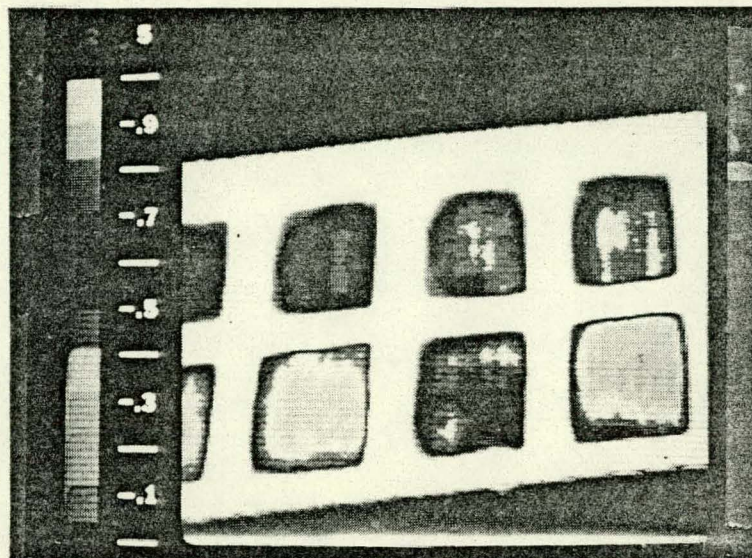


Fig. 2-1. Liquid Collector Thermograph

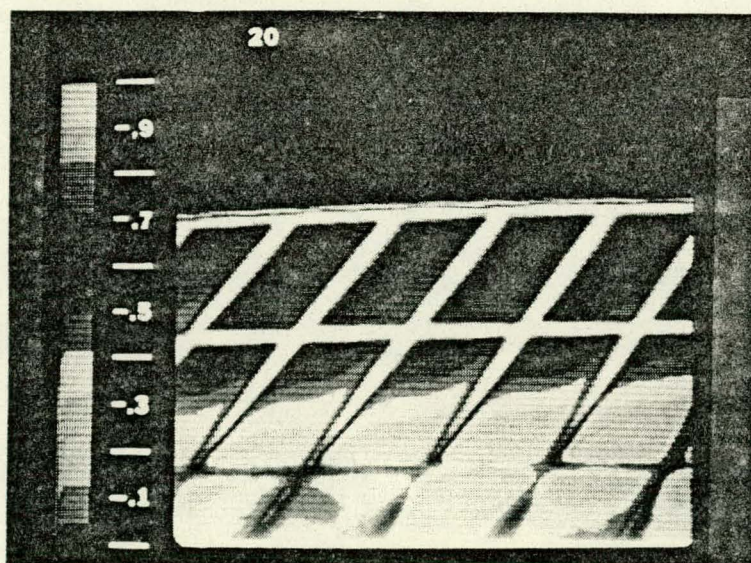


Fig. 2-2. Air Collector Thermograph

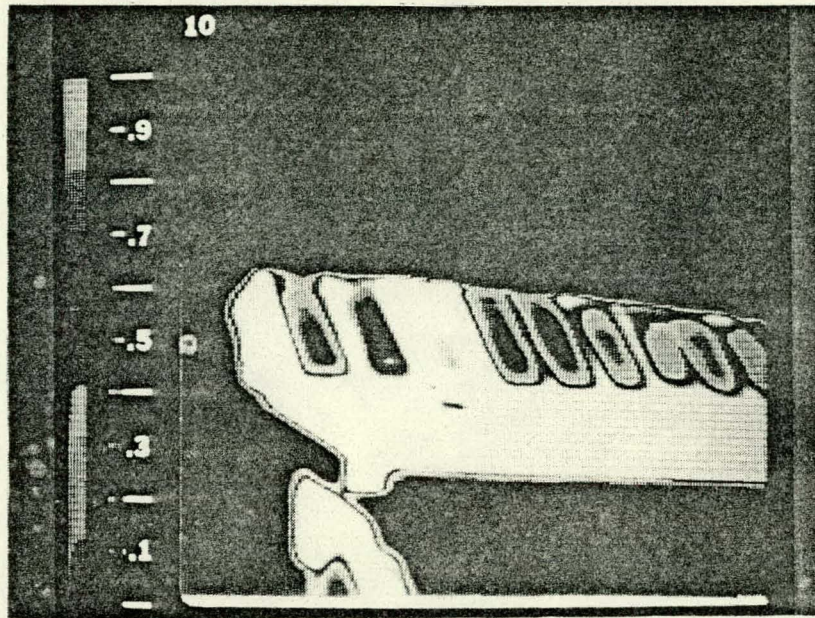


Fig. 3-1. Blocked Series Cluster

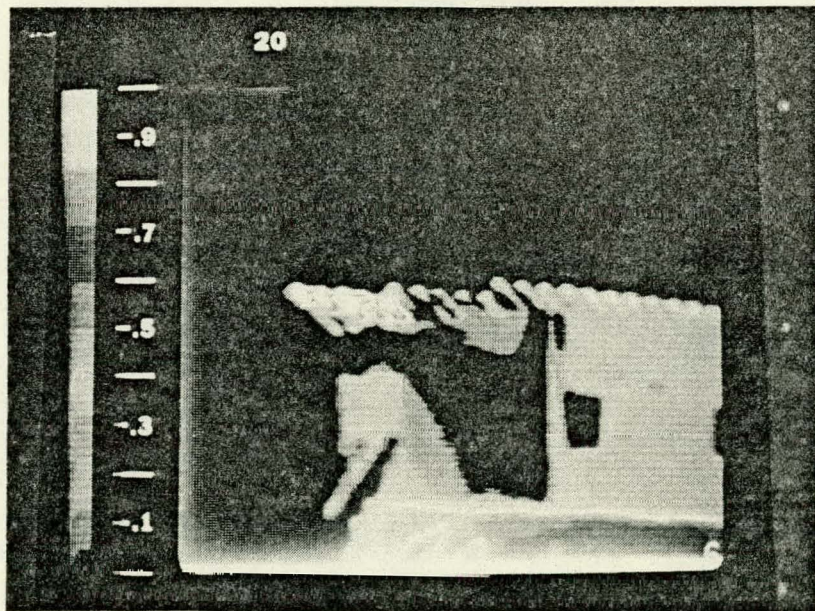


Fig. 3-2. Blocked Roof Array